

RECOMMENDATION ITU-R S.1420

**PERFORMANCE FOR BROADBAND INTEGRATED SERVICES DIGITAL NETWORK
ASYNCHRONOUS TRANSFER MODE VIA SATELLITE**

(Questions ITU-R 78/4 and ITU-R 75/4)

(1999)

The ITU Radiocommunication Assembly,

considering

- a) that satellites operating in the fixed-satellite service play an important role in providing reliable international digital communications;
- b) that, therefore, satellite performance must comply with performance objectives as specified by ITU-T Recommendation I.356-B-ISDN ATM layer cell transfer performance;
- c) that in defining performance criteria, it is necessary to take into account all the specific characteristics of the transmission medium used for asynchronous transfer mode (ATM) transmission,

recommends

- 1 that connection portions including satellite links carrying broadband integrated services digital network (B-ISDN) ATM transmission meet the objectives set forth in ITU-T Recommendation I.356 (see Note 1);
- 2 that these objectives should be met only during the time that the satellite link is in the available state (see Note 2);
- 3 that the reference model, set forth in Annex 1 of this Recommendation, be considered a basis for developing methods and techniques for meeting the objectives of ITU-T Recommendation I.356 in the above context;
- 4 that the allocations of ATM performance objectives to connection portions including satellite links forming part of a hypothetical reference connection (HRX) for B-ISDN ATM systems be according to the allocations set forth in Annex 1 of this Recommendation;
- 5 that the translation methods detailed in Annex 1 of this Recommendation be used in the assessment of performance levels of satellite systems designed to carry ATM traffic (see Note 3);
- 6 that the following Notes are regarded as part of this Recommendation.

NOTE 1 – Satellite transmission systems that carry ATM traffic but are not part of an international connection are outside the scope of ITU-T Recommendation I.356. In this case, performance objectives derived from ITU-T Recommendation I.356 may not apply.

NOTE 2 – The B-ISDN ATM availability objectives for semi-permanent connections are specified in ITU-T Recommendation I.357. The availability of B-ISDN ATM switched connections is for further study. Satellite system ATM availability parameters and objectives are the subject of Recommendation ITU-R S. 1424.

NOTE 3 – Annex 2 contains informative material regarding the general performance of ATM over satellites.

ANNEX 1

(Normative)

B-ISDN ATM layer performance objectives and translation methods for satellite links

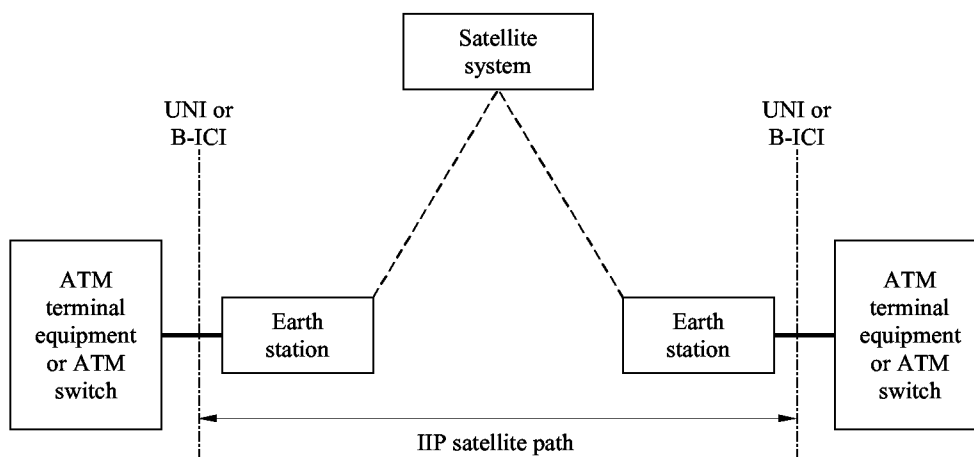
1 Scope

This Annex describes a reference model for the international portion of ATM satellite connections and details the methods for translating between the required ATM layer performance parameters and the satellite link bit error ratio (BER). Both the HRX definition and the ATM performance parameters of the various parts of the HRX are given in ITU-T Recommendation I.356. The use of satellite systems in other connection portions is a subject for further study.

2 Reference model

To interpret the allocation of performance objectives given to satellite portions of an ATM connection a reference model is provided in Fig. 1. Notice that the satellite path may comprise the earth stations and a single transparent (bent-pipe) satellite or a series of satellites. Some satellite systems may include on-board processors (OBPs), ATM switching, and inter-satellite links (ISLs). The terrestrial segment of the ATM satellite path comprises the earth station equipment (antennas, amplifiers, up-converters, down-converters, modems, etc.) and any satellite specific ATM equipment that may be used within a satellite path. The demarcation point between the domestic ATM network and the international ATM network is known as the measurement point international (MPI). The MPI can be a user-network interface (UNI) or a broadband inter-carrier interface (B-ICI). The portion between the two MPIs is known as the international inter-operator portion (IIP).

FIGURE 1
Reference model for an ATM satellite path



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One use of satellites is to provide connectivity between separate ATM networks located in different countries. In such case, the terrestrial ATM network will generally interface with the satellite subnetwork through an UNI (or B-ICI). Since this interface point may not always be co-located at the satellite earth station, there may be a terrestrial distance between the terrestrial gateway node and the earth station.

3 ATM performance objectives for satellite links

This section provides an interpretation of the performance objectives defined in ITU-T Recommendation I.356 and the corresponding requirements for the satellite portion(s) of an ATM connection.

The end-to-end ATM layer network performance parameters and objectives for public B-ISDN are defined in ITU-T Recommendation I.356. To accommodate the characteristics and the requirements of various traffic types, ITU-T Recommendation I.356 defines various classes of service. Class 1 (stringent class) is a delay-sensitive class and it is intended to support constant bit rate (CBR) and real-time variable bit rate (VBR) services such as telephony and videoconference. Class 2 (tolerant class) is a delay-tolerant class and supports available bit rate (ABR) and non-real-time VBR services such as video and data. Class 3 (bi-level class) supports VBR and ABR services such as high-speed data. Finally, Class 4 (unspecified class) supports unspecified bit rate (UBR) services such as file transfers and e-mail. Table 1 provides the ATM layer performance objectives for the various service classes (see Note 1). These objectives may be revised in the future based on operational experience (see Note 2).

NOTE 1 – During a recent meeting (June 1998) of Telecommunication Standardization Study Group 13 a new stringent bi-level quality of service (QoS) class was provisionally accepted for inclusion in the next version of ITU-T Recommendation I.356. This new class will have bounds for cell transfer delay (CTD), cell delay variation (CDV), cell loss ratio 0 (CLR₀), cell error ratio (CER), cell misinsertion rate (CMR), and severely errored cell block ratio (SECBR), but none for CLR₀ + 1.

NOTE 2 – Performance objectives designated by U are unspecified and the ITU will not establish an upper bound for these parameters.

TABLE 1

QoS class definitions and network performance parameters

	CTD	2-pt. CDV	CLR ₀₊₁	CLR ₀	CER	CMR	SECBR
Default objectives	No default	No default	No default	No default	4×10^{-6}	1/day	1×10^{-4}
<i>QoS classes:</i>							
Class 1 (stringent class)	400 ms	3 ms	3×10^{-7}	None	Default	Default	Default
Class 2 (tolerant class)	U	U	1×10^{-5}	None	Default	Default	Default
Class 3 (bi-level class)	U	U	U	1×10^{-5}	Default	Default	Default
U class	U	U	U	U	U	U	U

The QoS class required by each application is part of the contract negotiation procedure between the user and the network. If the network can provide the requested service level, the connection will be established. If there is any performance objective that cannot be met, the connection will be denied. Once a connection is established, the network must ensure that the performance objectives of the QoS class are met during the connection.

3.1 ATM performance allocation principles

ITU-T Recommendation I.356 specifies upper bounds on ATM transmission performance objectives. It allocates parts of the end-to-end objectives to the national and international portions of an HRX ATM connection. Geostationary satellites have a special allocation based on the assumption that satellites will replace significant terrestrial distance, multiple

ATM nodes and transit country portions. These performance allocations are defined between ATM measuring points as they refer to ATM transmission performance and not to individual items of transmission equipment such as satellite systems. Thus the allocation to the IIP includes terrestrial plant and may include ATM switching nodes as well as the satellite system.

This Recommendation assumes that the terrestrial plant does not introduce significant errors and that all the allocation can be given to the satellite system. Thus the objectives given in terms of ATM layer parameters at ATM measurement points simply need translation to the BER objectives of the satellite link. This assumption may not be valid, however, for all circuit configurations. Table 2 summarizes the allocation of objectives as specified in ITU-T Recommendation I.356 to connection portions with satellite links.

TABLE 2

**Allocation of ITU-T Recommendation I.356 objectives to
connection portions with satellite links**

	SECBR et CER (classes 1, 2 and 3 (%))	CLR (class 1) (%)	CLR (classes 2 and 3) (%)
National	42	35	34.5
IIP(0)	35	25	1
International transit portion	36	30	9
IIP(1)	38	30	11
IIP(2)	42	33	21
IIP(3)	48	42	31

According to ITU-T Recommendation I.356, the abbreviation IIP (x) ($x = 0, 1, 2 \dots$) is used to indicate a virtual channel (VC) IIP with x intervening transit countries, each providing virtual path (VP) switching or cross-connect functions.

3.2 ATM performance objectives for satellite systems

Numerical values of ATM performance parameters for satellite systems can be derived by applying the allocations given in Table 1 to the performance objectives given in ITU-T Recommendation I.356. As an illustration, the ATM performance objectives for a satellite link used in the international portion that provides Class 1 service and does not contain switching or cross-connect functions (see Note 1) are shown in Table 3.

NOTE 1 – The allocation of performance objectives for geostationary-satellite systems that include ATM switching and processing is for further study.

4 Translation between ATM layer and physical layer parameters

This section provides a mapping between the CLR, CER and SECBR ATM layer parameters and the BER of the satellite link. This section also discusses the other ATM layer parameters nominally: CMR, CTD and CDV and the impact of the satellite system characteristics on these parameters.

TABLE 3

ATM performance objectives for satellites (Class 1 services)

Performance parameters	ITU objective end-to-end	ITU objective satellite
CLR	$3 \times 10^{-7(1)}$	7.5×10^{-8}
CER	4×10^{-6}	1.4×10^{-6}
SECBR	1×10^{-4}	3.5×10^{-5}
CTD	400 ms	320 ms (maximum)
CDV	3 ms	Negligible
CMR	1 per day	1 per 72 hours ⁽²⁾

(1) It is possible that in the future, networks will be able to commit to a CLR = 1×10^{-8} for Class 1. This is for further study.

(2) The allocation for on-board ATM processing equipment is for further study.

4.1 Characteristics of satellite transmission errors

When geostationary orbit (GSO) satellites and fixed earth stations are used, the satellite transmission channel is Gaussian and transmission errors have a bursty nature owing to the scrambling and coding used in the satellite modems. Generally, the errors that emerge from a decoder tend to cluster in bursts according to the decoding algorithms employed. An error burst is defined by two parameters: the average burst length (L) and average number of bit errors per burst (N). Table 4 provides values of L and N for typical satellite error correction codes.

TABLE 4

Values of L and N for commonly used satellite error correcting codes

Error correcting code	Average burst length (L)	Average bit errors per burst (N)
R 3/4 convolutional coding with Viterbi decoding	29	11.5

The above values were obtained from empirical measurements of burst errors. Analytical derivations are possible for complex coding schemes but it is difficult to derive the results, and therefore measurements are needed to confirm the outcome.

4.2 CLR

The header error control (HEC) mechanism of ATM cells can correct single errors and detect almost all multiple-errors in the 5 bytes that contain the header of an ATM cell.

When the HEC detects errors that it cannot correct, the whole cell is discarded and its payload is lost. These discarded cells are the main component of the overall CLR parameter.

In the presence of randomly distributed errors, the single-bit error correcting code of the HEC is capable of correcting many of the errors encountered. In the presence of burst errors and assuming that the burst affects more than one bit of the header, then, no correction is possible since the HEC is capable of correcting only single bit errors. However, some patterns of multiple errors in the header can be misinterpreted by the HEC as a single error, and therefore an improper

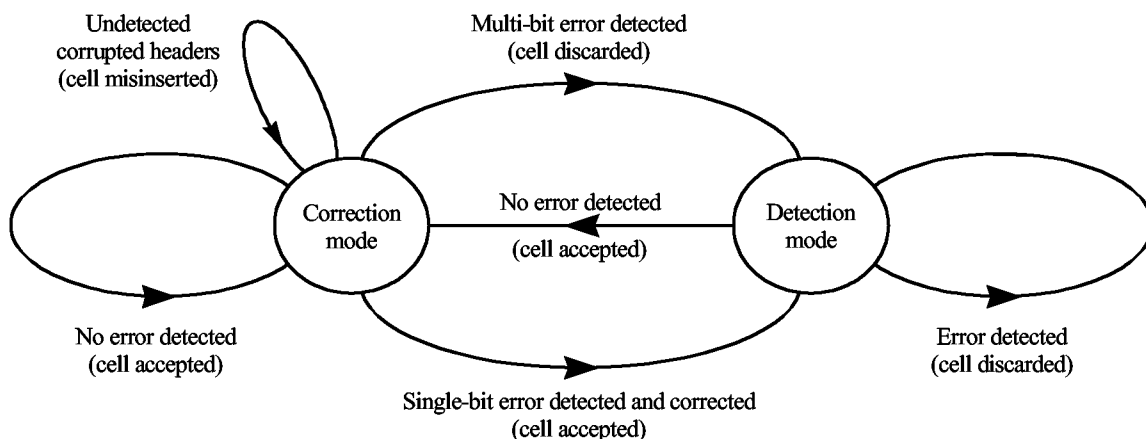
correction, or miscorrection, of the header may occur thus resulting in the cell not being discarded. In this case, the ATM cell is either eliminated or transmitted to the wrong destination by the next ATM node (misrouted). Although it is lost from an end-to-end connection, it may be counted as a correct cell by an ATM tester which is only adjusted to measure corrupted cells at the output of a satellite link. Misdirected cells will also contribute to the CLR if they are detected.

4.2.1 ATM HEC

The last octet in the 5-octet ATM cell header is an HEC byte which is used for header error detection and correction. As shown in Fig. 2, the ATM layer employs an ATM HEC mechanism that can operate in either correction mode or detection mode.

The ATM layer receiver normally operates in the correction mode, whereby all single bit errors are detected and corrected. All double and quadruple bit errors are only detected, and result in the cell being discarded. A small fraction of triple bit errors is mistakenly corrected as single bit errors. When in the correction mode, if a header error is detected (or corrected), the receiver switches to detection mode. In the detection mode, the ATM layer receiver is capable of detecting all single, double, and triple-header bit error patterns. It can also detect most quadruple bit error patterns. In the detection mode, no error correction is performed; all detected header errors result in cell discards. If no header errors are detected, when in the detection mode, the receiver switches to correction mode.

FIGURE 2
ATM cell header modes of operation



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4.2.2 Calculation of relationship between CLR and BER

In order to calculate how CLR relates to the BER, the following assumptions have been made about the cell loss outcome in the correction and detection modes:

- In correction mode, all multiple header error events result in cell loss. This assumption ignores the probability that undetected multiple errors, or multiple errors which are mistakenly corrected as single errors, may result in valid values in the header (and consequently a cell misinsertion outcome).
- In detection mode, all single or multiple header error events result in cell loss.

Based on the above assumptions:

$$P[\text{cell loss} \mid \text{correction mode}] \cong 1 - P[\text{no errors}] - P[1 \text{ error}]$$

$$P[\text{cell loss} \mid \text{detection mode}] \cong 1 - P[\text{no errors}]$$

and

$$P[\text{cell loss}] = P[\text{correction mode}] \times P[\text{cell loss} \mid \text{correction mode}] + P[\text{detection mode}] \times P[\text{cell loss} \mid \text{detection mode}]$$

Since the receiver will be in detection mode after every header error correction or detection:

$$P[\text{detection mode}] \cong 1 - P[\text{no errors}]$$

$$P[\text{correction mode}] \cong P[\text{no errors}]$$

Substituting in the above equation gives:

$$CLR = P[\text{cell loss}] \cong 1 - P[\text{no errors}] - P[\text{no errors}] \times P[1 \text{ error}]$$

Random error channel

For the random error channel:

$$P[\text{no errors}] = (1 - BER)^{40}$$

$$P[1 \text{ error}] = 40 \times BER \times (1 - BER)^{39}$$

Burst error channel

A first order characterization of the burst error channel is by the average burst length, L , and the average number of bits in error per burst, N . The probability of occurrence of a burst in a small interval corresponding to K bits may be approximated by $K \cdot BER/N$. Then, the probability that a burst overlaps a given bit ($K = 1$) may be approximated by:

$$P[\text{burst}] = BER/N$$

Assuming that only a single burst will impact the header, and error bursts do not extend over more than a single ATM header, the probability of no errors in the header is given by:

$$P[\text{no errors}] \cong 1 - (BER/N)(L - 1 + 40)$$

The probability of a single bit error in the header may be written as:

$$P[1 \text{ error}] = \sum Pe(i) P[\text{burst}]$$

where $Pe(i)$ represents the occurrence of a single error in a certain bit i , given that a burst hits that bit; the summation must consider all the cases where the burst overlaps the header.

Figure 3a) illustrates the situation where a single error in the header at position $i \leq \text{minimum}(L - 1, 39)$ corresponds to the last (errored) bit of the burst. (Note that an error burst begins and ends with a bit in error).

Assuming a uniform and independent distribution of errors within the burst (excluding the first and last bits), for the case in Fig. 3, $Pe(i) = [1 - P(EB)]^i$, where $P(EB)$ is the probability of a bit being in error between the first and last bits of the burst. This is given by:

$$P(EB) = (N - 2)/(L - 2)$$

A symmetric topology may be obtained by considering that the single error at position i is produced by the first (errored) bit in the error burst, as also illustrated in Fig. 3b). Then, the probability of a single error in the header is given by:

$$P[1 \text{ error}] \cong (BER/N) \times 2 \times \sum [1 - P(EB)]^i$$

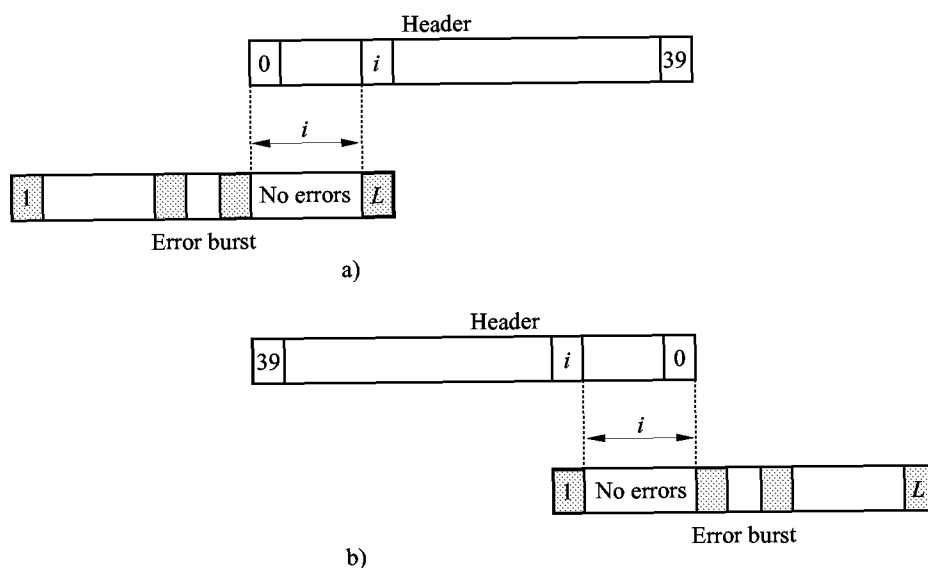
where in the above summation, $i = 0, 1, \dots, \text{minimum}(L - 1, 39)$. For typical values of N and L ($N, L \gg 1$):

$$P[1 \text{ error}] \cong (BER/N) \times 2/P(EB)$$

Note that, if $L > 40$ and the header is entirely contained in the burst, there may be a possibility of a single error being produced by a bit error not corresponding to the first or last bit in the burst. The probability of this event is much smaller than the one described previously and is neglected. Also note that if $L \leq 40$ and $L - 1 < i \leq 39$, the burst is entirely inside the header and, in that case, at least two errors will occur.

FIGURE 3

Single error in header produced by the last and first (errored) bits in the burst



Shaded portion represents error bit in burst.

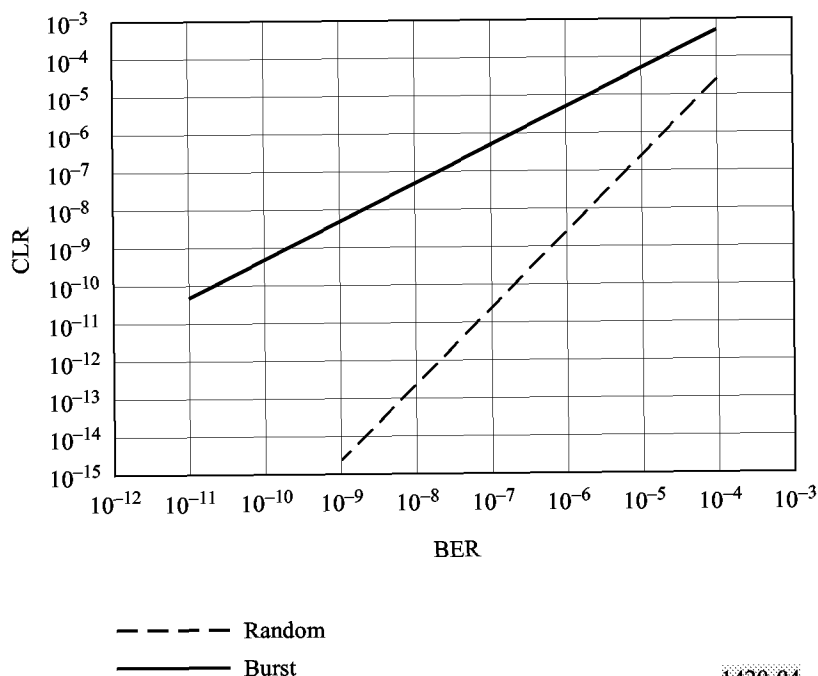
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4.2.3 Numerical results

A plot of CLR versus BER is provided in Fig. 4. This plot shows CLR for a random error environment and for a burst error environment where $L = 29$ and $N = 11.5$ (typical of rate 3/4 convolutional encoding with Viterbi decoding).

FIGURE 4

Plot of CLR as a function of BER for a burst error channel with average length, $L = 29$ and average number of bits in error per burst, $N = 11.5$



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Some measured results for concatenated codes may be found in § 3 of Annex 2.

4.3 CER

The CER is defined as the ratio of errored cells to the total number of successfully transferred errored and non-errored cells. A successfully transferred cell is defined as a cell that is received with a correct (virtual path identifier/virtual channel identifier) (VPI/VCI) and a valid HEC byte. Therefore, not counting misinserted cells, an errored cell event would occur if:

- the cell header contains detected errors;
- the cell HEC corrected a multiple bit error as a single bit error which resulted in an incorrect VPI/VCI; and
- the cell header is correct while the cell payload contains one or more bit errors.

The probability of the first two events has been ignored in comparison with the probability of a payload error event. Taking into account the receiver header error correction mode and detection mode, the CER can be expressed as:

$$P[\text{cell error}] = P[\text{cell error} | \text{correction mode}] \times P[\text{correction mode}] + P[\text{cell error} | \text{detection mode}] \times P[\text{detection mode}]$$

where:

$$P[\text{detection mode}] \cong 1 - P[\text{no header errors}]$$

$$P[\text{correction mode}] \cong P[\text{no header errors}]$$

4.3.1 Calculation of relationship between CER and BER

- In order to calculate how CER relates to BER, the same assumptions used to derive the CLR relationship to BER were used: In correction mode, all multiple header error events result in cell loss.
- In detection mode, all single or multiple header error events result in cell loss.

Based on these assumptions, the probability of a cell error in correction and detection modes is:

$$P[\text{cell error} | \text{correction mode}] = (1 - P[\text{cell loss} | \text{correction mode}]) \times$$

$$P[\text{payload error} | \text{correction mode}] \cong P[(\text{no header errors}) + P[1 \text{ header error}]] \times$$

$$P[\text{payload error} | \text{correction mode}]$$

$$P[\text{cell error} | \text{detection mode}] = (1 - P[\text{cell loss} | \text{detection mode}]) \times$$

$$P[\text{payload error} | \text{detection mode}] \cong (P[\text{no header errors}]) \times$$

$$P[\text{payload error} | \text{detection mode}]$$

The CER is:

$$P[\text{cell error}] = P[\text{payload error} | \text{correction mode}] \times (P[\text{no header errors}] + P[1 \text{ header error}]) \times P[\text{no header errors}] + P[\text{payload error} | \text{detection mode}] \times (P[\text{no header errors}]) \times (1 - P[\text{no header errors}])$$

Random error channel

For the random error channel:

$$P[\text{no header errors}] = (1 - BER)^{40}$$

$$P[1 \text{ header error}] = 40 \times BER \times (1 - BER)^{39}$$

$$P[\text{payload error} | \text{correction mode}] = P[\text{payload error} | \text{detection mode}] = 1 - (1 - BER)^{384}$$

Burst error channel

For the burst error channel with average burst length L and average error bits per burst N :

$$P[\text{no header errors}] \cong 1 - (BER/N) \times (L - 1 + 40)$$

$$P[1 \text{ header error}] \cong (BER/N) \times \left[\sum (1 - PEB)^i + \sum (1 - PEB)^{39-i} \right]$$

where in the above summation, $PEB = (N - 2)/(L - 2)$ and $i = 0, \dots, \text{minimum}(L - 1, 40 - 1)$.

When the receiver is in the correction mode, a valid cell is received if there are 0 or 1 header error bits. The probability of a payload error depends on whether a HEC occurred. When there are 0 header error bits, the probability of a payload error is the probability of a burst error within the payload, which is approximated by:

$$PB \cong 384 \times BER/N$$

On the other hand, when there is 1 header error bit which is corrected by HEC, the single error bit will be either the first bit or the last bit of an error burst. When the header error bit is the first bit of an error burst, the probability of a payload error is approximately equal to 1. When the header error bit is the last bit in an error burst, the probability of a payload error is PB. Therefore, in correction mode:

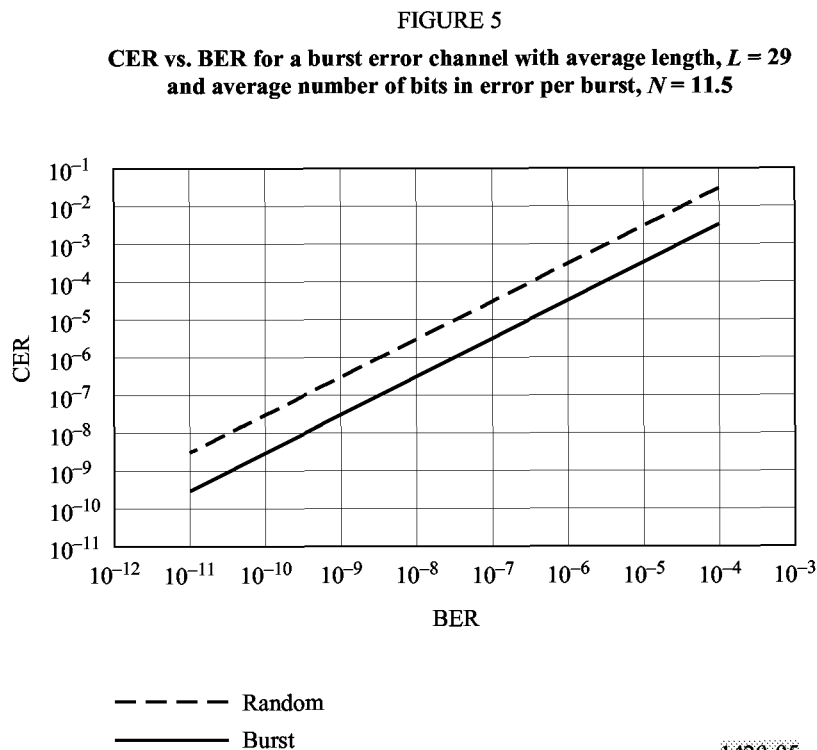
$$P[\text{payload error} | \text{correction mode}] \cong P[\text{no header errors}] \times PB + P[1 \text{ header error}] \times [0.5 + 0.5PB]$$

In detection mode, a valid cell is received only if no header errors occurred. The probability of a payload error is given by:

$$P[\text{payload error} | \text{detection mode}] \cong P[\text{no header errors}] \times PB$$

4.3.2 Numerical results

A plot of CER versus BER is provided in Fig. 5. This plot shows CER for a random error environment and for a burst error environment where $L = 29$ and $N = 11.5$ (typical of rate 3/4 convolutional encoding with Viterbi decoding).



Some measured results for concatenated codes may be found in § 3 of Annex 2.

4.4 SECBR

The SECBR parameter is defined in ITU-T Recommendation I.356 as the ratio of total severely errored cell blocks to total cell blocks in a population of interest. A severely errored cell block outcome occurs when more than M errored cells, lost cells, or misinserted cell outcomes are observed in a received cell block. A cell block is a sequence of N cells transmitted consecutively on a given connection. The values of M and N are rate dependent and are given in Table 1 of ITU-T Recommendation I.356.

4.5 CMR

Certain patterns of multiple errors in the header node may be recognized by the HEC as single errors and hence the affected cell can be miscorrected instead of being discarded. In this case, the next ATM node may either drop the cell or send it to the wrong destination (misrouted). Within ITU-T Recommendation I.356, the parameter that accounts for the total number of misinserted cells observed during a specified time interval is the CMR.

4.6 CTD

The overall CTD or latency within a satellite connection results from various sources. The main source of delay is free-space propagation. The next contributor is the delay due to coding and decoding done at the satellite channels (modems). Generally, coding delays vary depending on the type of coding and the transmission bit rate. Finally, another source of delay may be the satellite specific ATM equipment located at the earth station or on board the spacecraft as they may introduce queuing, switching and/or routing delays.

4.7 CDV

The CDV or jitter that may arise in a satellite link depends on several aspects. First, CDV depends on the traffic load structure or the number and proportion of virtual path (VP) and virtual channels (VC) that may be used within the ATM channel. CDV also depends on the switch buffering capacity and mechanism. Next, CDV will increase with the number of ATM nodes within a connection (this may be a critical component of satellites that use OBP and ISL). Finally, CDV will depend on the amount of internal switch operations (queueing, switching, routing) resulting from satellite specific ATM equipment. The use of multiple access schemes may have an impact on CDV.

5 Relationship between ITU-T Recommendations G.826 and I.356 performance parameters

While the ATM layer performance parameters and objectives are specified by ITU-T Recommendation I.356, the physical layer performance parameters and objectives for connections that will carry ATM traffic are given in ITU-T Recommendation G.826 – Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate. The ITU-T Recommendation G.826 performance parameters are errored seconds ratio (ESR), severely errored seconds ratio (SESR), and background block error ratio (BBER). Furthermore, the performance objectives of ITU-T Recommendation G.826 are rate dependent. A satellite link within a ITU-T Recommendation G.826 connection is allocated 35% of the overall end-to-end objectives.

Studies and measurements on channels affected by error bursts have shown that a satellite system designed to just meet ITU-T Recommendation G.826 may not meet the ITU-T Recommendation I.356 objectives for ATM Class 1 services. Thus, it is essential that satellite links that will carry ATM traffic be designed to meet ITU-T Recommendation I.356 requirements with additional margin to ensure compliance with ATM QoS requirements.